SOIL COMPACTION IN URBAN AREAS DEPENDING ON LAND USE: CASE STUDY IN CLUJ-NAPOCA, ROMANIA

Păuniţa Boancă[1]*, Adelina Dumitraş[1], Sonia Bors-Oprișa[1], Laura Luca[1], Laczi Enikő[1], Andrei Mărincean[1], Ion Roșca[2]

[1]*Univeristy of Agricultural Sciences and Veterinary Medicine, Faculty of Horticulture, Mănăştur St.3-5, 400372, Cluj-Napoca, Romania;* [2]*Botanical Garden of the Academy of Sciences of Moldova, Chisinau, Republic of Moldova; *corresponding author: paunita.boanca@usamvcluj.ro*

Abstract. Water infiltration in the soil is restricted in the urban area by the large impervious surfaces and the soil compaction. We conducted the experiments to determine if the urban soils are subject to accentuated compaction even in the permeable areas and if necessary implement is the bioretention systems to improve water and soil quality. We conducted the experiments under the same conditions of soil moisture for all the sites (four sites - different in terms of land use: industrial, low-density residential, high-density residential and commercial). Degree of compaction was determined with a digital electronic cone penetrometer. We established nine penetration points were for each site. In order to determine the degree of compaction we calculated the percentage of values that exceeded 2086.5 kPa (300 psi) in the first 45 cm. The results defined soils as slightly compacted - uncompacted in the commercial area; slightly compacted in the high-density residential area; moderately compacted in the low-density residential area; severely compacted in the industrial area. We concluded that compaction affects the soils regardless of the land use in urban areas.

Keywords: runoff, pervious, urban, sites, quality, infiltration

INTRODUCTION

Restoring the urban soil quality and reduce compaction, often involves many obstacles and can be especially problematic because the improvement works cannot be carried easily in areas where there are mature vegetation, underground utilities, buildings, traffic routes. This is important in the low impact development strategies, which provide a faster infiltration and drainage of the stormwater runoff than the traditional systems (Gregory et al., 2006). The compaction has various negative effects on soil and environment (Viehmeyer and Hendrickson, 1948; Harris, 1971; Craul, 1994; Harris et al., 1999;

Chen et. al, 2013; Chen et al., 2014; Mohd Idris and Cameron, 2016). Generally, compaction is a problem in the first 30.5 cm of surface soil layer. Compaction varies depending on soil type and the thereof water content at the time of testing (Schuler et al., 2000). To determine whether a soil is compacted or not and if measures are needed to improve the structure, the degree of compaction must firstly be quantified. Within urban soils, there is a high degree of variability (Craul, 1994; Jim, 1998) due to the presence of residues resulting from anthropic activities as well as large amounts of stone. Randrup (1997) showed that loamy soils in built urban sites were compacted to a depth of 0.8 m. Soil compaction in urban areas is one of the negative factors that can be improved by implementing sustainable drainage systems (bioretention systems) that have the capacity to improve the soil structure and manage surface rainwater runoff (Josimov-Dundjerski et al., 2015; Kazemi et al. 2011; Trowsdale and Simcock, 2011; Barbosa et al. 2012; Mangangka et al. 2015).

The aim of this study is to evaluate the degree of soils compaction in four sites, which are different in terms of land use, and to determine whether permeable surfaces are subject to accentuated compaction. The study is justified by the fact that the process of the soil compaction depreciates the infiltration capacity and leads to increased surface rainwater runoff along with the related consequences. The experiment started from the following hypothesis: the soil in the urban environment of Cluj-Napoca are subject to enhanced compaction even in the pervious areas, which depreciates the infiltration capacity and leads to an increase in the pluvial surface leakage and to the consequences associated with this accentuation.

MATERIAL AND METHODS

Studied area. Cluj-Napoca is found at the central area of Transylvania, in the Someș Mic Corridor, with an area of 179.5 km². It is located at the intersection of parallel 46°46'N with meridian 23°36 'E. We performed the measurements in four sites that are different in terms of land use: a commercial area, an industrial area, a low-density residential area, and a high-density residential area (Figure 1).

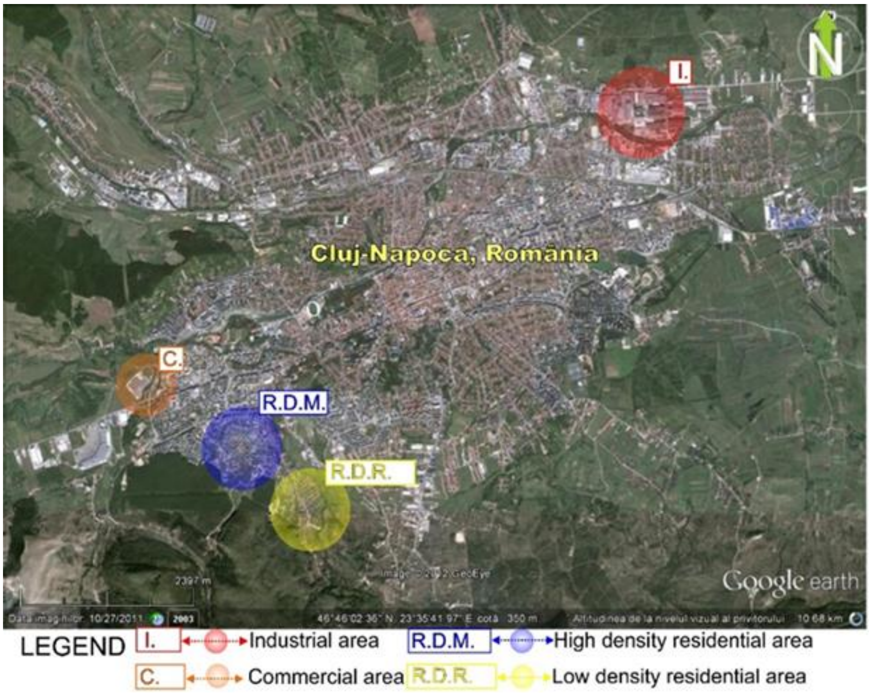

Fig. 1. The map of the studied sites

Determination of soil compaction. In order to determine the degree of compaction was used the digital electronic penetrometer (Field Scout^{TM}SC 900) with cone. In this experiment, we used the following units: kPa and cm. We carried out the experiments under the same soil moisture conditions for all the sites. In each studied site, we carried out a geotechnical drilling to determine the degree of permeability and the structure of the soil. We performed an equal number of nine measurement points on each site. We estimated the compaction using two methods in an effort to exclude the errors. The first method is based on the determination of the percentage of the total values in which the compaction resistance was greater than 2086.5 kPa (300 psi). The same value (2068.5 kPa - 300 psi) Pitt et al. (2002) consider it also in defining the compacted soils. The second method of assessing the soil compaction in the studied areas is based on the grid used by Murdock et al. (1995), which involves calculating the percentage of points in which values exceed 2086.5 kPa (300 psi) in the first 45 cm. Following this pattern, we calculated the averages of the values recorded in each measurement point from a location, after this being assessed the percentage of the points in which the average value is > 2086.5 kPa (300 psi).

RESULTS AND DISCUSSIONS

Of the 36 penetration performed in the four sites not all have reached the maximum depth of the penetrometer - 45 cm (Figure 2-5).

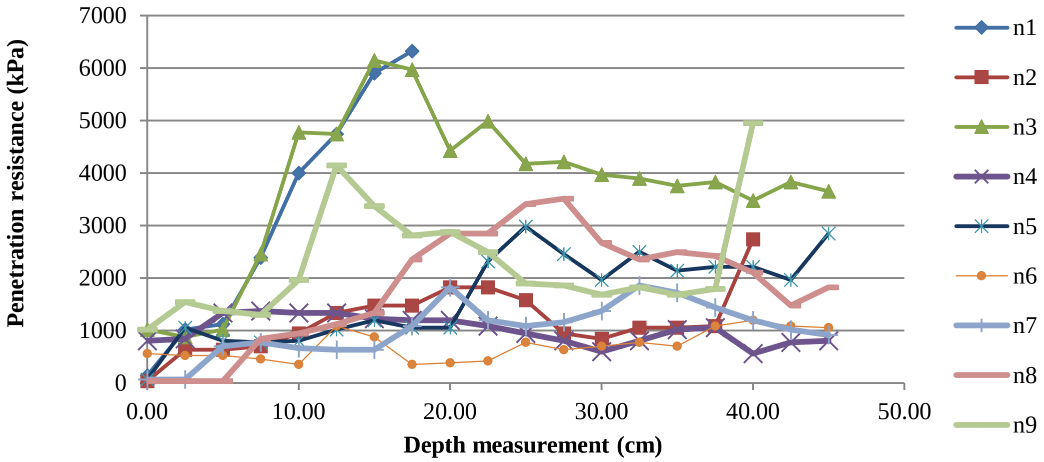

Fig. 2. Fluctuation of penetration resistance value. Commercial area, Cluj-Napoca, Romania

The results show constant low values (under 2068.5 kPa) for all points only in the first five cm. Starting with the depth of 7.5 cm, the values oscillates ranging between 702 kPa and 6320 kPa. This shows that there is severely compacted layers interspersed with slightly or medium compacted layers. In the high-density residential site (Figure 3), the number of points in which the measurement of the values has not reached the depth of 45 cm is higher in comparing with the commercial site (Figure 2). This indicates an increased soil compaction in the high-density residential site. The average values of the resistance in the measurement points from the low density residential area indicates a severe compaction starting with the depth of 7.5 cm, while the analysis of the maximum values in depth shows a severe compaction starting at the depth of 5 cm (Figure 4). In the industrial area were not reached the maximum depth of measurement nor a point of nine (Figure 5).

Murdock et al. (1995) assessed the degree of compaction of soils by calculating the percentage of the points in which values are greater than 2086.5 kPa (300 psi) in the first 45 cm. In our research, we evaluated the soils modifying this model - we considered the percentage of values exceeding 2086.5 kPa of the total values recorded at nine points in the first 45 cm of soil. We opted for this type of evaluation because values ranged in depth and in the measurement points.

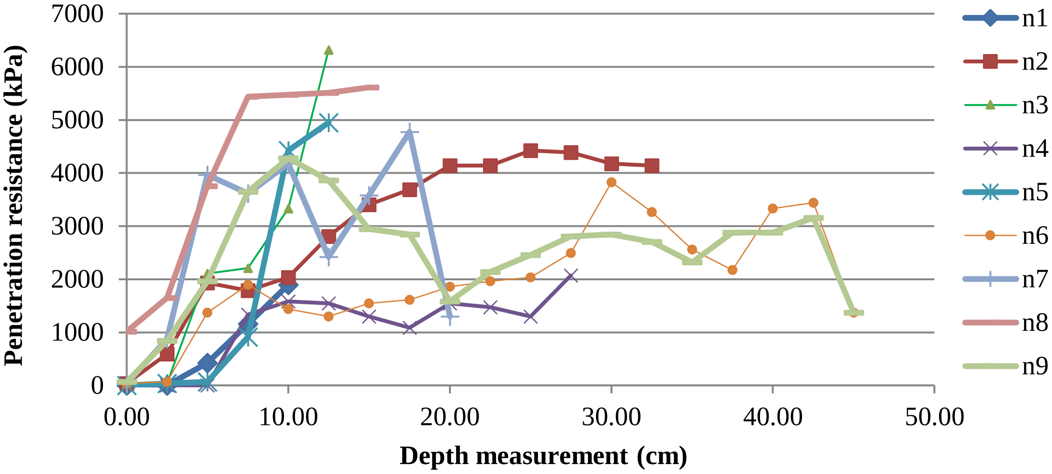

Fig. 3. Oscillations of penetration resistance value, High-density residential area, Cluj-Napoca, Romania

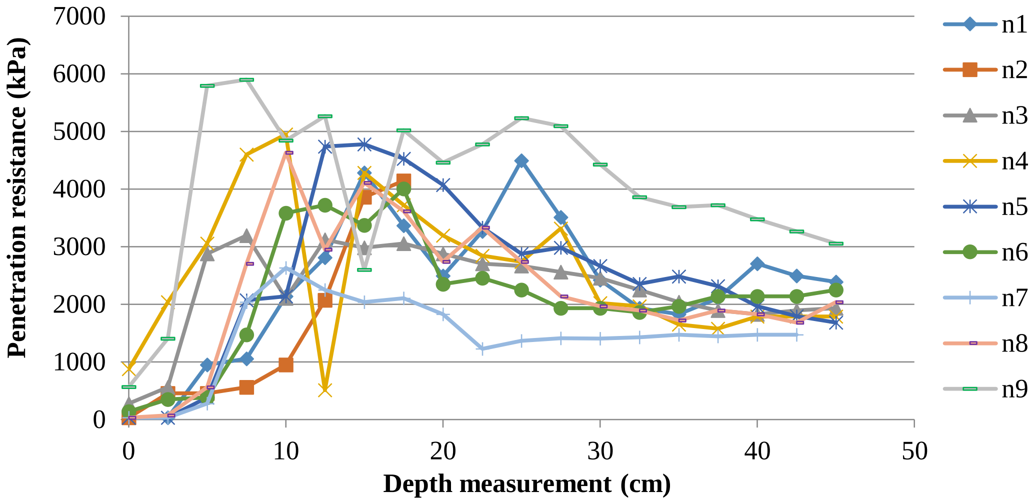

Fig. 4. Oscillations of penetration resistance value. Low-density residential area, Cluj-Napoca, Romania

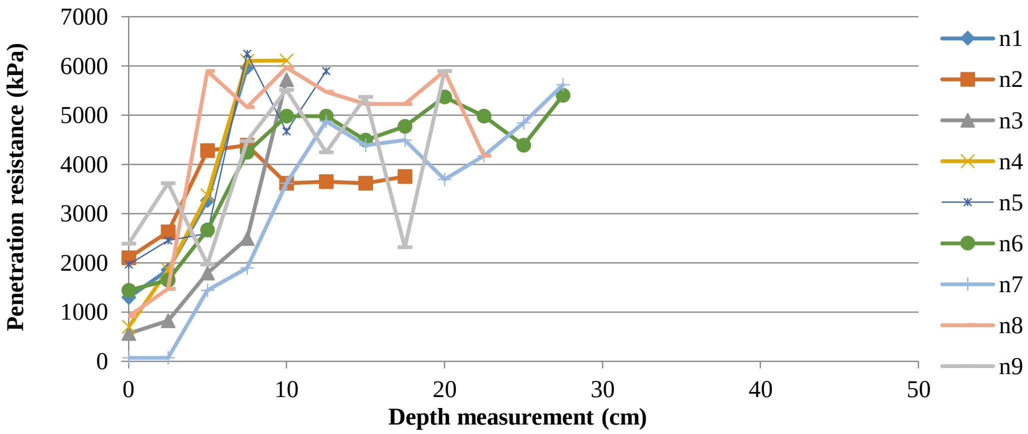

Fig. 5. Oscillations of penetration resistance value. Industrial area, Cluj-Napoca, Romania

Thus, we consider the percentage of values> 2086,5 kPa (300) calculated from the total number of values registered in a site to be characteristic. The classification of the soils from the studied sites, using the Murdock et al. method, differ only for the low-density residential area. In the low-density residential area the percent of the points in which values are greater than 2086.5 kPa (300 psi) is 78%, characterizing the soil as severely compacted. For the other sites, the method for assessing the compaction after the percentage of the points did not change the characterization made earlier based on the percentage of the values (Figure 6). Pitt et al. (2002) states that the use of the bioretention for the control of the stormwater runoff can restore the conditions existing prior to the development of urban areas.

The results confirmed the hypothesis from which we started the research of this condition of the implementation of the bioreactor cells - the compaction of the soils from the urban environment of Cluj-Napoca. Based on this result, we can state that the studied urban environment has the same problems in terms of soil degradation, as the big cities where much attention is paid to this aspect - there is a large number of research on the influence of urban soil characteristics on stormwater runoff (Pearson et al., 2013; Pouyat et al., 2007).
Pitt et al. (2002) states that the use of the bioretention for the control of the stormwater runoff, especially in the low and medium density urban area, can restore the conditions existing before the development of these areas. Compaction of urban soils is mainly due to the construction activities and the type of land use (Pitt et al., 2002). Involuntary soil compaction at the scale of urban sites is a process that reduces infiltration rates, which can lead to increased rainfall volume. This is particularly important in low impact development strategies that imply that storm infiltration is faster than drainage through traditional systems (Gregory et al., 2006).

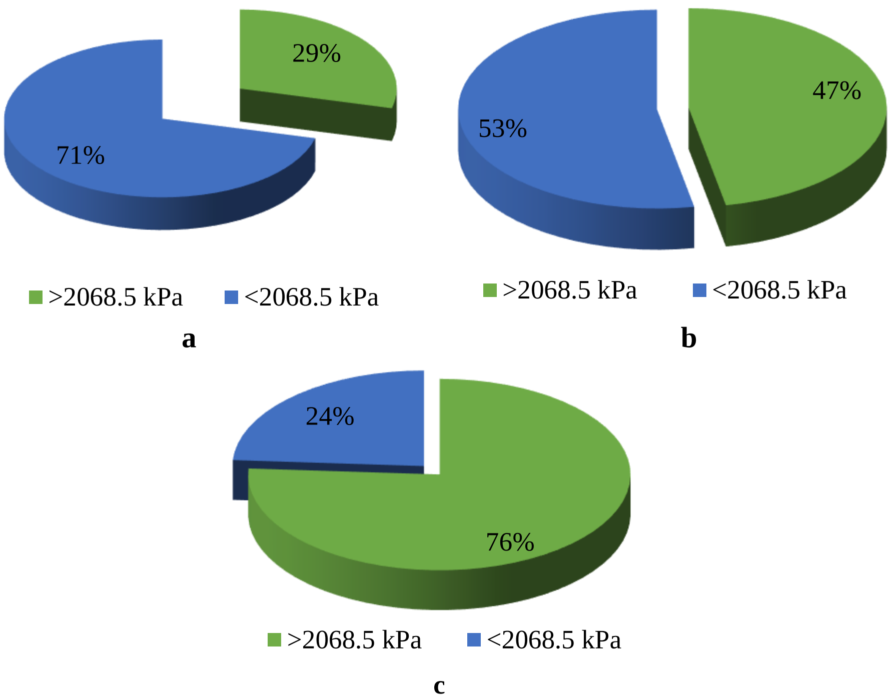

Fig. 6. Percentage of values exceeding the limit of 2086.5 kPa, at: a) Commercial area, Cluj-Napoca; b) High density residential area, Cluj-Napoca; c) Industrial area, Cluj-Napoca

CONCLUSIONS

The studied urban areas encounters problems in terms of land degradation. Two of these sites are facing a severe compaction while only one show slight compaction. Analysing in terms of spatial variability, there is a link between the land use, location of study sites in Cluj-Napoca and their degree of compaction. The degree of compaction of the soil is another prerequisite local showing that the implementation of bioretention cells is a viable solution for improving the existing conditions and that can participate to the goals of sustainable development in Romania (bioretention cells or SUDS being tested practices that can solve the problems derived from urban soils compaction).

Acknowledgments. The Integration of Green Infrastructure in Urban and Peri-Urban Landscape through Sustainable Spatial Planning/INFRAGREEN, European and International Cooperation Subprogram 3.1. Bilateral/multilateral.

REFERENCES

1. Barbosa, A.E., Fernandes, J.N., David, L.M. (2012): Key issues for sustainable urban stormwater management. Water Research, 46(20):6787-6798.
   doi: https://doi.org/10.1016/j.watres.2012.05.029
2. Chen, Y., Day, S.D., Wick, A.F, Strahma, B.D., Wiseman, P.E., Daniels, W.L. (2013): Changes in soil carbon pools and microbial biomass from urban land development and subsequent post-development soil rehabilitation. Soil Biology and Biochemistry, 66, 38-44.
   doi: https://doi.org/10.1016/j.soilbio.2013.06.022
3. Chen, Y., Day, S.D., Wick, A.F., McGuire, K.J. (2014): Influence of urban land development and subsequent soil rehabilitation on soil aggregates, carbon, and hydraulic conductivity. Science of the Total Environment, 494-495:329-36.
   doi: https://doi.org/10.1016/j.scitotenv.2014.06.099
4. Craul P. (1994): Soil compaction on heavily used sites. Journal of Arboriculture, 20(2), 69–74.
5. Gregory, J.H., Dukes, M.D., Jones, P.H., and Miller, G.L. (2006): Effect of urban soil compaction on infiltration rate. Journal of Soil and Water Conservation, 61(3), 117-124.
6. Harris, R.W., Clark, J.R., Matheny, N.P. (1999): (3rd ed.) Arboriculture: Integrated Management of Landscape Trees, Shrubs and Vines. Prentice Hall, New York, NY., p. 687.
7. Harris, W.L. (1971): The soil compaction process. Barnes, K.K. (Ed.), Compaction of Agricultural Soils, An ASAE Monograph, American Society of Agricultural Engineers, St. Joseph, MI., p. 471.
8. Jim, C.Y. (1998): Physical and chemical properties of a Hong Kong roadside soil in relation to urban tree growth. Urban Ecosystems, 2, 171–181.
   doi: https://doi.org/10.1023/A:1009585700191
9. Josimov-Dundjerski, J., Savić, R., Belić, A., Salvai, A., Grabić, J. (2015): Sustainability of the constructed wetland based on the characteristics in effluent. Soil and Water Research, 10: 114–120. doi: 10.17221/133/2014-SWR
10. Kazemi, F., Beecham, S., Gibbs, J. (2011): Streetscape biodiversity and the role of bioretention swales in an Australian urban environment. Landscape and Urban Planning, 101(2):139-148. doi: https://doi.org/10.1016/j.landurbplan.2011.02.006
11. Mangangka, I.R., Liu, A., Egodawatta, P., Goonetilleke, A. (2015): Performance characterization of a stormwater treatment bioretention basin. Journal of Environmental Management, 150:173-178. doi: https://doi.org/10.1016/j.jenvman.2014.11.007
12. Mohd Idris, N.I. Cameron, R.W.F. (2016): Root and shoot development in ornamental shrubs: the influence of compacted soil and altered root geometry. Acta Horticulturae, 1108, 2013-219. doi: 10.17660/ActaHortic.2016.1108.27
13. Murdock, L., Gray, T., Higgins, F., Wells, K. (1995): Soil Compaction in Kentucky, Cooperative.

14. Pearson, B.J., Beeson, R.C., Reinhardt-Adams, C., Shober, A. (2013): Determining variability in characteristics of residential landscape soils that influences infiltration rates. Arboriculture and Urban Forestry, 39(6): 249-255.
15. Pitt, R., Shen-En Chen, Clark, S. (2002). Compacted Urban Soils Effects on Infiltration and Bioretention Stormwater Control Design. 9th International Conference on Urban Drainage, IAHR, IWA, EWRI, and ASCE.
16. Pouyat, R.V., Yesilonis, I.D., Russell-Anelli, J., Neerchal, N.K. (2007): Soil Chemical and Physical Properties That Differentiate Urban Land-Use and Cover Types. Soil Science Society of America Journal, 71 (3): 1010–1019. doi:10.2136/sssaj2006.0164
17. Randrup, T.B. (1997): Soil compaction on construction sites. Journal of Arboriculture, 23(5), 207-210.
18. Schuler, R.T., Casady, W.W., Raper, R.L. (2000), Soil compaction. Chapter 9. R.C. Reeder (ed.) MWPS special publication: Conservation tillage systems and management.
19. Trowsdale, S.A., Simcock, R. (2011): Urban stormwater treatment using bioretention. Journal of Hydrology, 397(3–4):167-174. doi: https://doi.org/10.1016/j.jhydrol.2010.11.023
20. Viehmeyer, F.J., Hendrickson, A.H. (1948): Soil density and root penetration. Soil Science, 65(6):487-494.